Factors Related to Delta Smelt Salvage at South Delta Pumping Plants and Implications of Entrainment Losses to the Delta Smelt Population

Abstract

CALFED programs including the Ecosystem Restoration Program, the South Delta Program, and the Water Management Strategy address the issue of entrainment of delta smelt at CVP and SWP pumping plants in the south Delta. An analysis of salvage, fish survey and hydrology data from 1980-1999 indicates the magnitude of delta smelt salvage at south Delta pumping plants is related to export rate, outflow, net flows in the lower San Joaquin River, seasonal delta smelt life history factors, and delta smelt population abundance and distribution. Many of the specific salvage events in the past two decades can be explained by these factors. The combination of seasonally decreasing outflow and increasing exports explain many of the major smelt salvage events. Many of the specific salvage events that occurred historically and likely led to the decline in delta smelt would not occur under existing water quality standards, biological opinions, and AFRP actions such as VAMP. Proposed new CALFED programs such as the ERP and EWA, along with new CVPIA actions (e.g., b2, b3) could further reduce the entrainment risk to delta smelt.

Introduction

Entrainment of fish, particularly delta smelt a listed threatened species under the Endangered Species Act, at the CVP and SWP pumps in the Delta has been identified by CALFED as one of twelve issues dealing with uncertainties that relate to the choice of a through-Delta alternative. *"More information on the effects of entrainment and altered hydrodynamics will be pivotal in choosing a water conveyance method, because it will help determine to what extent an isolated facility can be expected to alleviate any problems."* CALFED's Delta Entrainment Fish Team and the Water Management Development Team are evaluating means for operating the SWP and CVP projects to minimize entrainment of delta smelt. Analysis of available smelt distribution data in the Delta in combination with Delta hydrology and pumping plant salvage data may provide some insights into operational schemes that will reduce entrainment effects on the delta smelt population.

Salvage data for delta smelt from 1980 to 1999 were analyzed to determine potential factors related to salvage. Factors reviewed included outflow rate, export rates, QWEST, and smelt distribution and abundance within the Bay-Delta. All data were obtained from the Interagency Ecological Program Internet site. Analysis generally consisted of reviewing the data plots and charts. Limited statistical analysis was conducted using data analysis tools available in Microsoft Excel spreadsheet program.

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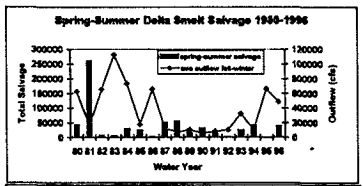
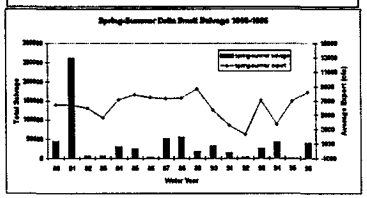
Gross Seasonal Patterns and Relationships

An initial review was made of spring-summer salvage patterns corresponding to the juvenile life-stage of delta smelt and fall-winter salvage patterns corresponding to the pre-spawning and spawning adult stages.

Spring-Summer

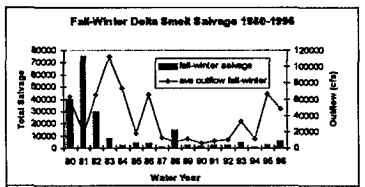
Salvage of juvenile smelt from April through September is generally lower in wettest years (1982, 1983, 1986, and 1995). Wet winters shift the distribution of adult spawning smelt downstream from the Delta away from the Delta pumping plants. Young smelt are then more abundant in downstream areas because more are spawned downstream or are transported as larvae downstream by high outflow. Total salvage over the spring and summer shows little relationship to total export. Low salvage in 1992 may have been related to the lower export rate.

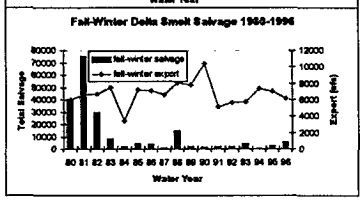




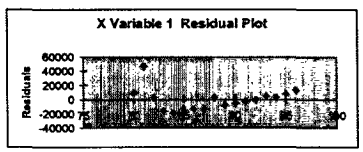
Fall-Winter

Salvage of adult smelt from fall through winter appears related to population abundance and distribution. High salvage in the early 1980's was probably related to greater population abundance as determined from abundance indices from the fall mid-water trawl and summer tow-net surveys (IEP 1999). Winter FWS beach seine collections from the Delta showed a similar pattern of abundance. Fall-winter salvage appears unrelated to fall-winter exports with the possible exception of 1984, which had low salvage and low exports.





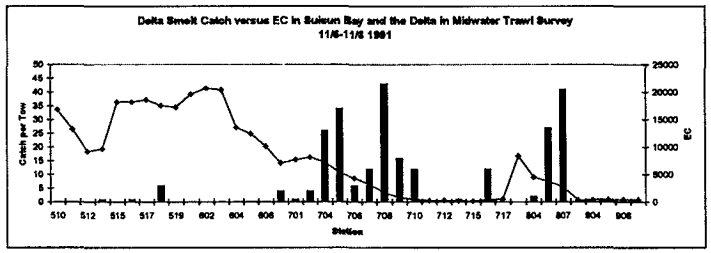
Regression analysis showed a significant negative relationship between fall-winter delta smelt salvage and year. A plot of the residuals of the regression shows a strong sequential pattern that suggests an initial sharply falling population in the early 1980's and a long gradual recovery through 1996.



Specific Seasonal Analyses

Fall

Smelt Distribution. In the fall of 1991, a very dry year, brackish water was distributed upstream into the western Delta including the lower Sacramento River (Stations 704-710) and the lower San Joaquin River (Stations 804-810), but not as far as the mouths of Old and Middle River (Stations 904-906). Very few smelt were collected in Suisun Bay (Stations 510-701) where EC was approximately 8,000-20,000.

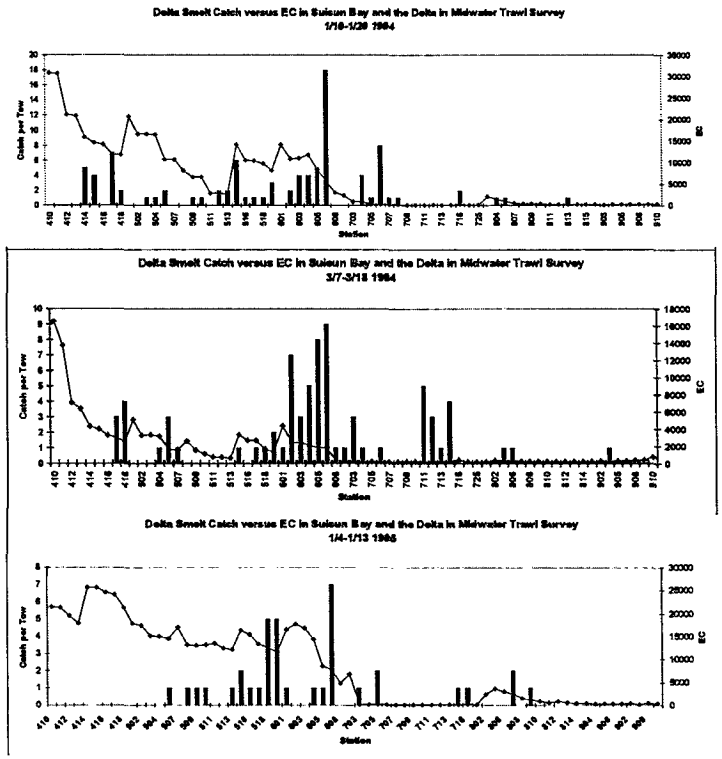


Smelt Salvage. Despite most of the smelt population residing in the western Delta including the lower San Joaquin River throughout the fall, very few smelt are salvaged. Fall salvage is generally very low regardless of year, population abundance, outflow, and export rate. The reason appears to be the close affinity of delta smelt at this life stage for low-salinity habitat, which is typically just downstream of the influence of the Delta export facilities at this time of the year. Because the water export system goes to great strides to minimize exporting brackish water, few delta smelt are salvaged at the fish facilities of the pumping plants in the fall. Outflow and exports also tend to be very stable in the fall, which also appears to minimize salvage. Susceptible fish living in the south Delta also may have been entrained by the end of the summer.

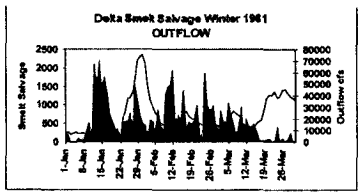
Winter

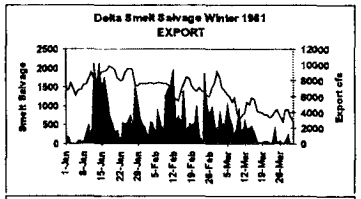
Smelt Distribution. In winter many adult smelt remain concentrated in slightly brackish water, while others move upstream further into freshwater to spawn.

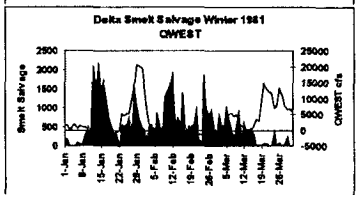
Trawl surveys in 1994 and 1995 provide a distinct picture of delta smelt winter distribution. Most adult smelt were distributed through Suisun Bay (stations 410-603), Montezuma Slough (stations 604-608), the lower Sacramento River between Collinsville and Decker Island (stations 701-706), and the lower San Joaquin River (stations 802-806). Some delta smelt moved upstream in the lower Sacramento River channel to Cache Slough (stations 711-715), a known spawning ground.



1981 Salvage. The highest fall midwater trawl population index of delta smelt of the 80's and 90's occurred in the fall of 1980. The highest salvage of delta smelt after 1980 occurred in 1981. Salvage rose sharply in early winter before flow rose to higher winter peaks and under relatively high export rates (>8,000 cfs).

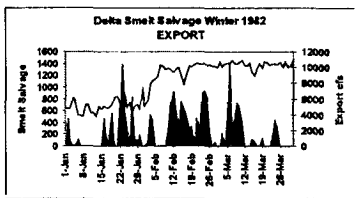


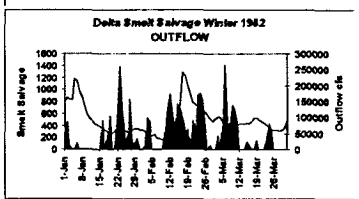


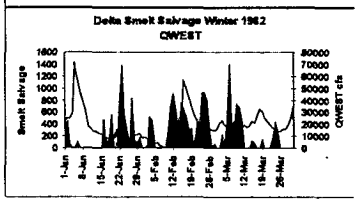


The combination of high export rate and low outflow combined to produce negative QWEST flow through the first three weeks of January. Peaks in salvage in mid January and at the end of February followed drops in outflow and QWEST. Under such conditions, adult smelt are apparently drawn toward the south Delta pumping plants. The salvage peaks in February after a high outflow period (70,000-cfs) indicates that significant adult smelt salvage events can reoccur during the winter if flow drops and exports are moderate to high (>6,000 cfs). In March, low salvage levels coincided with high outflow and lower export rates.

1982. Salvage was relatively high again in 1982 – a wet year with a moderate population size based on summer townet and fall midwater trawl indices. Winter flows were very high in 1982. Despite high flows there were peaks in salvage in late January, mid and late February, and early March. These peaks coincided with moderate to high export rates (>6,000 cfs) and falling outflow and QWEST. The two latter peaks occurred despite outflow near or above 100,000 cfs, but under high export levels (>10,000 cfs). Salvage was lowest during and immediately after outflow and QWEST peaks.



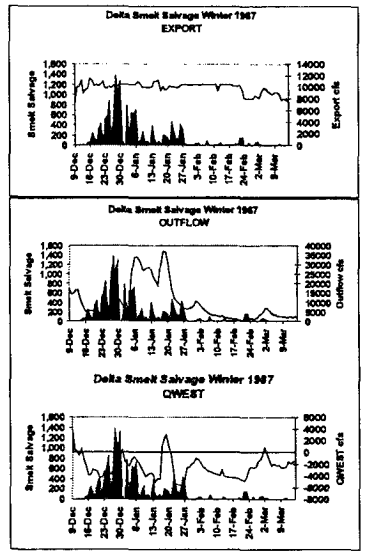




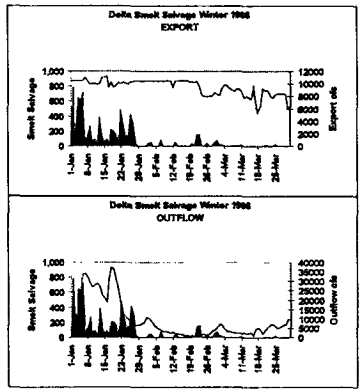
1983-1986. After 1982, salvage was very low through the wet period 1983-1986. These were also low abundance years.

1987-1992. Low abundance generally continued through the drought period 1987-1992. Salvage numbers were also generally low compared to the early 1980's. However, in some drought years winter salvage was sporadically high relative to the low population abundance.

1987. The winter of 1987 was one of these years with relatively high salvage of adult delta smelt in early winter despite a low population level. The peak salvage period coincided with a period of low outflow, high exports, and negative QWEST. Salvage remained low in February and March despite high exports and low outflow.

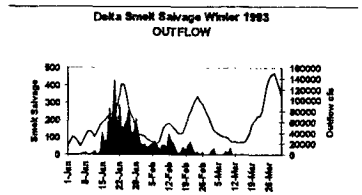


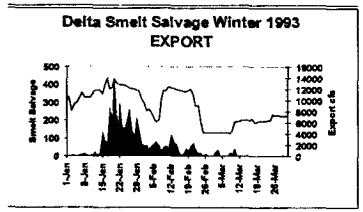
1988. In 1988 peak salvage occurred in the first week of the year under high export rates and low outflow (near zero). Salvage declined in the second week of January when outflow increased sharply to 30,000 cfs. Salvage increased slightly in late January as outflow fell under continuing high export rates. Salvage remained low through February and March despite high exports and low outflow.



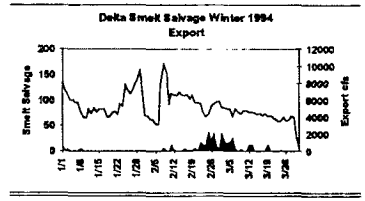
1989-1992. Winter salvage of adult delta smelt was low under low population levels during the drought years of 1989-1992. Salvage peaks (not shown) generally corresponded to periods of high export in combination with low outflow. Winter pulses in outflow generally led to lower salvage as in 1987. Late winter salvage was generally very low as in 1987 and 1988 despite high exports and very low outflow.

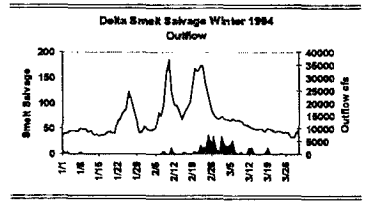
1993. In 1993, a relatively high outflow year, the peak period of salvage corresponded to a period of very high export rates (12,000-14,000 cfs) during a test of the new pumps at the Banks plant. Outflow during the period of peak salvage in the latter half of January was 60,000-130,000 cfs. Salvage was low in February and March under higher outflows and lowering exports. With San Luis Reservoir filling in late February, exports were reduced to lower winter delivery levels.

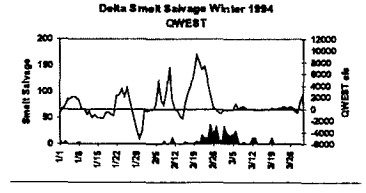




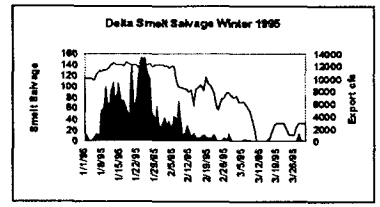
1994. Adult smelt were salvaged in low numbers during the winter of 1994. Numbers were likely low due to smelt being concentrated in Suisun Bay downstream of the Delta (see earlier discussion of 1994 winter smelt distribution) and relatively low exports and stable outflow for most of the winter.

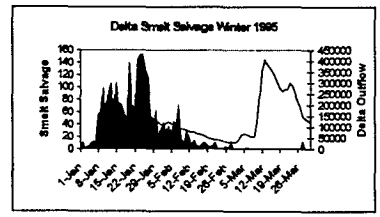






1995. In the winter of 1995 adult smelt salvage was moderate through early winter under high export rates. Though the winter was classified as wet, outflow was relatively low initially in January. Salvage increased sharply under high exports (10,000-12,000 cfs) before a sharp increase in outflow and continued despite relatively high flows (>100,000 cfs). Salvage dropped sharply when export rates fell below 8,000 cfs. High exports rates under initially lower outflow likely were a factor in drawing the adult smelt to south Delta early in the winter. Sharply higher flows through the middle of January did not reduce salvage. As in previous years, salvage was low in February despite higher exports and falling outflows. March salvage was negligible under high outflow and very low exports.





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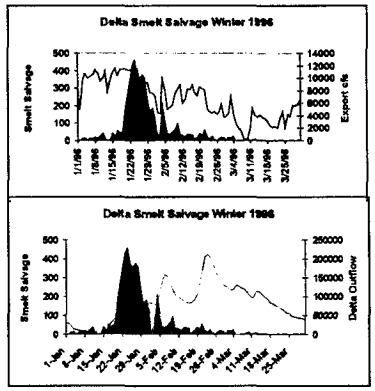
1996. In the winter of 1996, another wet winter, salvage of delta smelt adults again began prior to increases in outflow and continued into a period of high outflow. As in 1995, salvage rose sharply at moderate outflows (<50,000 cfs) then declined as outflows increased to near 100,000 cfs and the export rates fell below 8,000 cfs.



1997. In the winter of 1997 (not shown), which began with the huge New Year's flood, salvage rates were similar to 1995 and 1996 with a peak coinciding with an increase in exports at the beginning of March to near 15,000 cfs (see page 27, IEP 1999).

1998. In 1998 (not shown), salvage numbers were very low under low exports (<5,000 cfs) and high outflow.

Summary of Winter Salvage Patterns. In summary, higher winter salvage of delta smelt appears related to higher export rates (generally 8,000-14,000 cfs), and low or sharply dropping outflow. Salvage events occurred in wet and dry winters. Winter salvage appears to commence in late December or early January often before the peak flows of winter and under high export rates. Salvage rates appear related to population abundance. Salvage often dropped by February or March even under high exports and low outflows. The winters of 1981 and 1982 were exceptions as under high exports (1982) or low outflow (1981) salvage rates were high. The higher population level in 1981 and 1982 may have also contributed to the higher salvage levels in these years. Salvage also dropped in late winter of wet years to low levels when exports rates declined under high outflow after San Luis Reservoir filled and exports were limited to deliveries.

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Spring-Summer

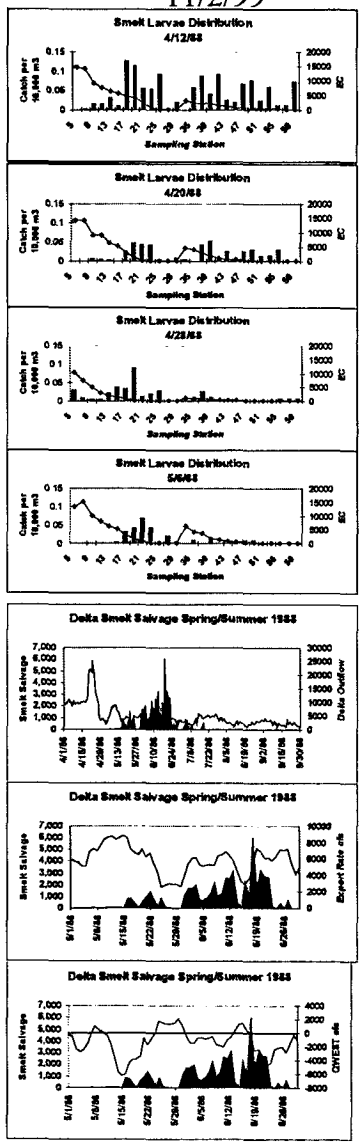
Larval smelt are present through the spring, but are not salvaged because of their small size. Some juvenile smelt begin showing up in salvage in May as they grow to salvageable size (over 20 mm). Prior to reaching salvage size, larval smelt are entrained through the louvers of the fish facilities at the south Delta pumping plants and are lost to the canal systems. Most young smelt have usually attained juvenile size by early summer.

Critical Dry Years.
Critical dry years since 1980 included 1988, 1990, 1991, 1992, and 1994. Two examples, 1988 and 1994 are described below to represent the general patterns of spring-summer salvage of juvenile smelt for critical years.

1988. A typical, critical year distribution of larval and early juvenile smelt occurred in 1988. Smelt young were captured in the IEP egg and larvae survey from early April into June. Larvae were concentrated in the lower Sacramento River (stations 20-29) and the lower San Joaquin River (stations 35-60). Densities dropped off further west into Suisun Bay (stations 5-19) where EC increased above 5000. Larvae also were present at the eastern extent of sampling at the mouth of the Old and Middle Rivers (stations 59 and 60).

By early May young smelt were concentrated in slightly brackish water of the lower Sacramento River between Collinsville (station 17) and Decker Island (station 26). Lesser concentrations occurred in the lower San Joaquin River.

Coincident with the transformation of larvae to juveniles, salvage of juvenile smelt began to increase in mid May. Relatively high levels of salvage occurred from mid May through late June. Peaks in the first three weeks of June coincided with low and declining outflow, peaks in exports of 6,000-8,000 cfs, and negative QWEST flows. Outflow fell to near zero in mid May and mid June. Summer townet survey data (not shown) indicated very low abundance with a distribution similar to the May larval distribution.



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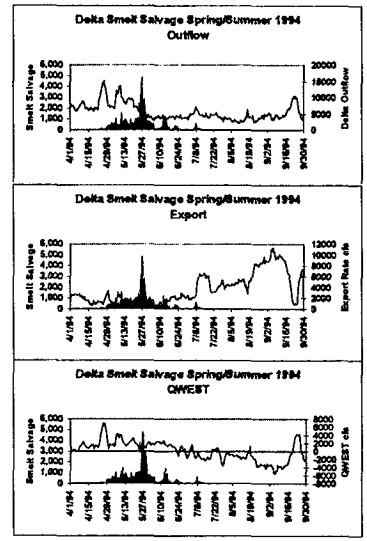
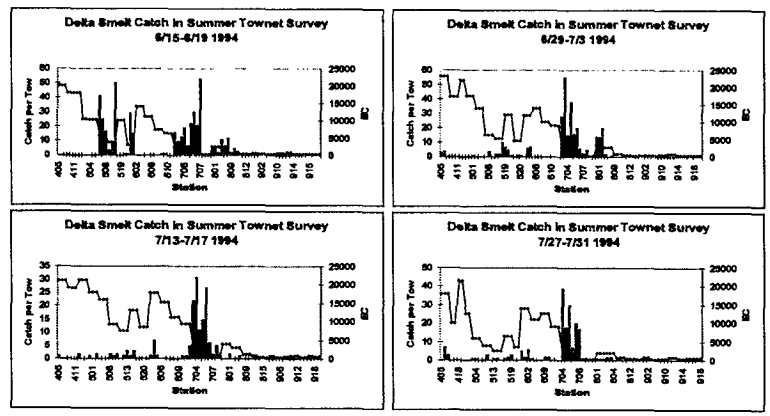
1994. In 1994, another critical water year, smelt salvage was low by early summer. The peak in salvage at the end of May coincided with rapidly falling outflow, QWEST falling to zero, and low but rising export rate.

Low export rates through July appeared to keep young delta smelt from being drawn up into the central and southern Delta. Salvage was very low through July despite the delta smelt population being concentrated in the western Delta and lower Sacramento River.

Summer townet surveys found the smelt concentrated from mid-June through July at the front of brackish water in eastern Suisun Bay (stations 506-520), the lower Sacramento River (stations 704-707), and the lower San Joaquin River (stations 801-809). Very few smelt occurred in the central and southern Delta (stations 810-918).





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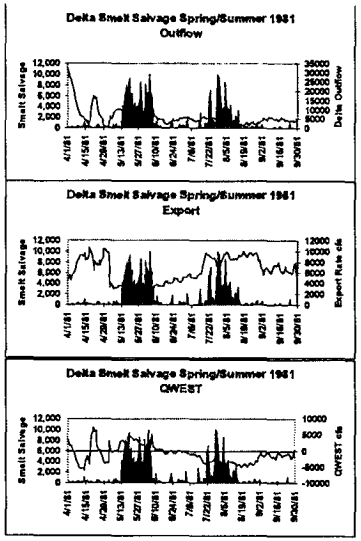
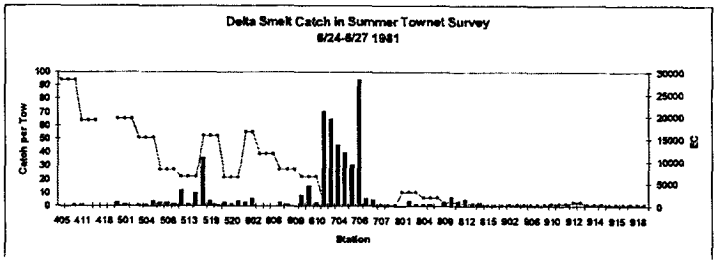
Below Average – Dry Years
Years 1981, 1985, 1987, and 1989 are classified as dry years. Moderate winter outflow and low spring outflow best exemplify these water years. Two examples, 1981and 1989 are described below to represent the general patterns for dry years.



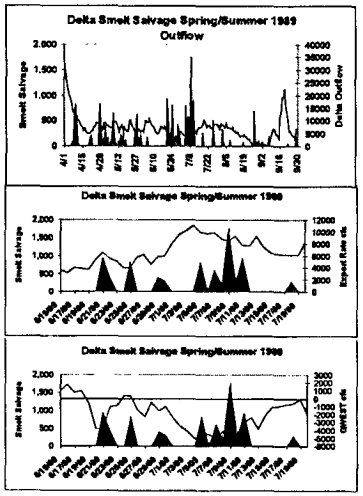
1981. As stated earlier, 1981 followed a very high abundance year for delta smelt. High winter salvage rates described earlier continued with high spring and summer salvage of juvenile smelt. High salvage rates began in mid-May under moderate outflow (10,000-15,000 cfs) and exports (4,000-6,000 cfs). Most likely young smelt reaching a salvageable size caused this event. Larval and early juvenile smelt (non-salvageable sizes) were likely drawn to the south Delta earlier in April and early May when exports were high and outflow low.

Salvage declined sharply in early June as outflow stabilized and exports remained moderate. During June juvenile smelt were highly concentrated in the lower Sacramento River from Collinsville (station 513) to Decker Island (station 706), Honkers Bay (station 519), and the upper end of Montezuma Slough (station 610). Lower densities occurred in western Suisun Bay (stations 405-504) and the lower San Joaquin River from Antioch to the mouth of Old River (stations 804-815).



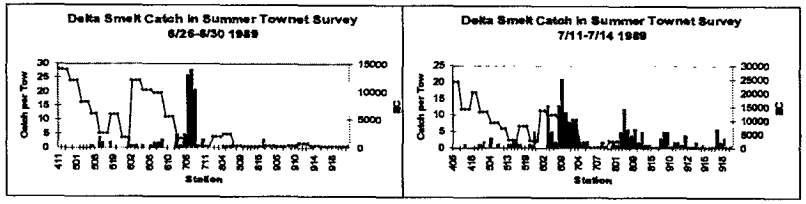
Salvage increased sharply in mid July coincident with a sharp increase in export rates and a corresponding fall in QWEST under steady but low outflows. Smelt appeared to have been drawn from the lower San Joaquin and western Delta by the high export rates. A summer townet survey in late July (not shown) showed a similar distribution as that from late June, except that very few smelt were collected in the lower San Joaquin River.

1989. In 1989, another dry year, a very similar pattern occurred although densities and salvage numbers were much lower than in 1981.



Salvage peaks in early summer in 1989 coincided with high export rates, very low outflow, and negative QWEST levels.

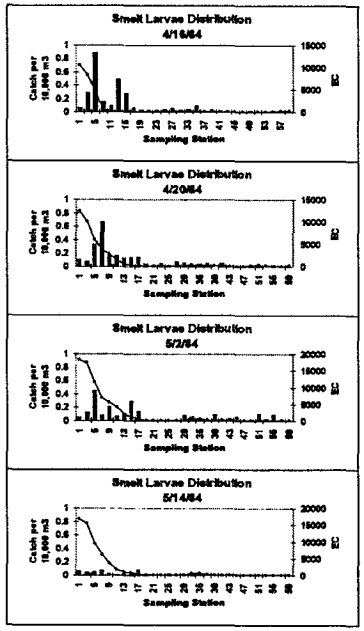
The two summer townet surveys in the summer of 1989 lend some insight into the events. Smelt were concentrated in the lower Sacramento River (stations 704-711) in late June. By the second week in July, smelt were still concentrated in slightly brackish water in Montezuma Slough (stations 606-610) and distributed upstream in the lower San Joaquin (stations 804-812) and into Old and Middle Rivers (stations 902-918). It would appear that the high export rates in combination with increasing salinity in Suisun Bay and highly negative QWEST flows beginning early in July drew smelt from the western Delta into the south Delta where they were vulnerable to salvage at the pumping plants.



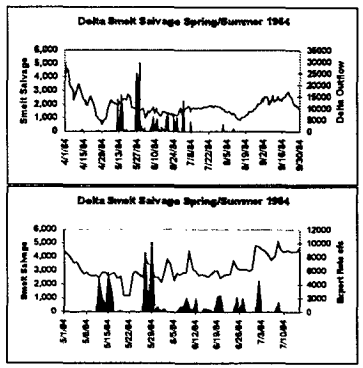
1985 and 1987. Salvage patterns in 1985 and 1987 (not shown) were very similar to those of 1989. Each year had several events with near or higher than 1,000/day salvage. Peak salvage events were generally coincident with sharply dropping outflow, increasing or steady exports, and falling and near zero or negative QWEST.

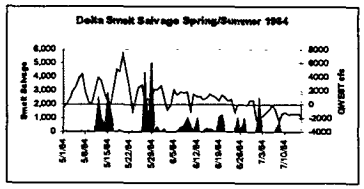
Average Years.
There were two average or median water years since 1980: 1984 and 1993. Year 1984 is classified a wet year for the Sacramento Valley and an above-normal year for the San Joaquin Valley. Year 1993 is classified an above normal year for the Sacramento Valley and a wet year for the Sacramento Valley.

1984. In 1984 the distribution of smelt larvae during the spring was further downstream than in a dry year like 1989 discussed earlier. Smelt larvae were concentrated in Suisun Bay (stations 1-15). As in 1989 they were concentrated at the head of the brackish water zone; however in 1984 this zone was much further downstream. Larvae were present upstream as far as the eastern extent of sampling near the mouth of Old River (station 59) in the lower San Joaquin River and to Rio Vista (station 29) on the lower Sacramento River. By mid-May densities had declined to low levels and smelt larvae were concentrated in Suisun Bay.



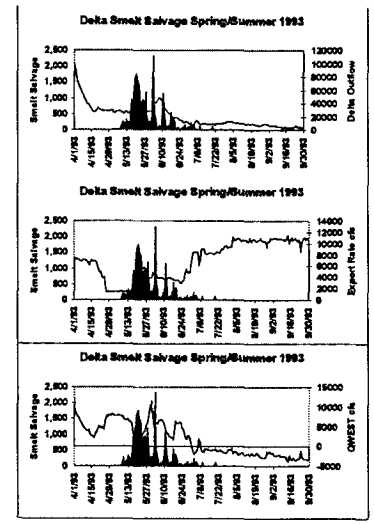
Coinciding with the decline in larvae in 1984, juvenile smelt began to appear in salvage collections. Smelt were sporadically salvaged into early July. Peaks in salvage in mid and late June were associated with falling outflow, lower QWEST, and moderate to high (and increasing) export rates (6000-8000 cfs).

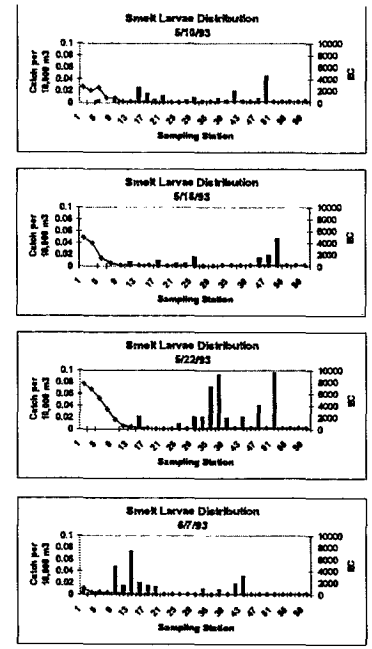




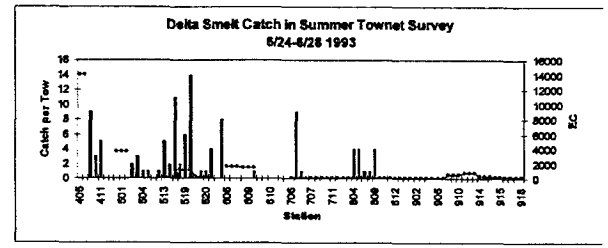
1993. Year 1993 was another median year. However, compared to 1984, larvae were less abundant and distributed further upstream through the freshwater zone of the Delta as far as the mouth of Old River through late May despite relatively high Delta outflow.

Smelt salvage peaked in the later half of May coincident with higher exports and sharply falling outflow and QWEST. Small peaks in June coincided with sharp drops in QWEST.





Juvenile smelt from late June into July were concentrated in Suisun Bay (stations 418-520), Montezume Slough (stations 606-610), the lower Sacramento River (stations 704-707), and the lower San Joaquin River (stations 804-812).



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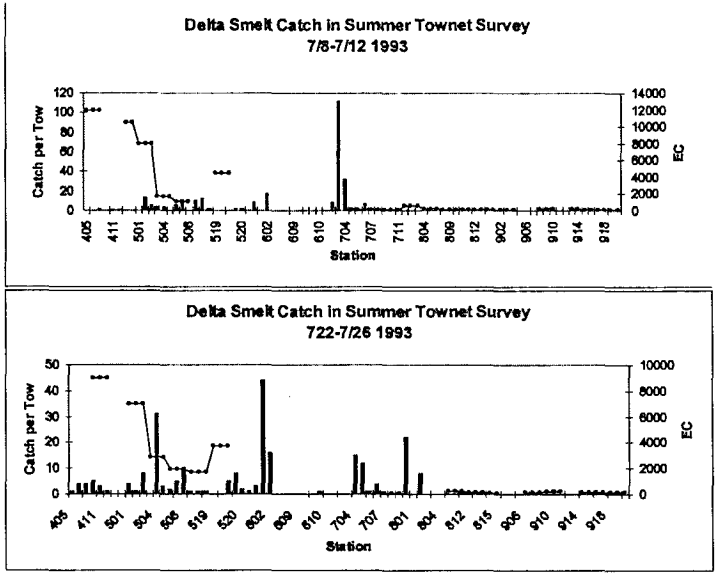


The low export rate (4000 cfs) through June in combination with a relatively high outflow and QWEST served to keep smelt distributed in the western Delta and Suisun Bay, and minimized salvage losses at the south Delta pumping plants.

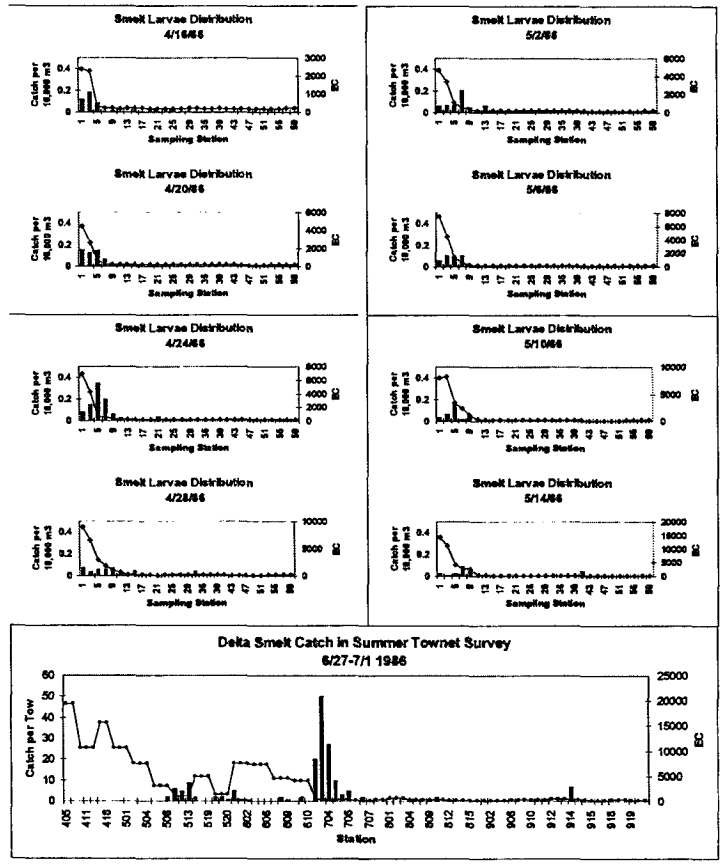
When exports rose sharply in July and outflow and QWEST declined, salvage losses were low as smelt were distributed well into Suisun Bay and the western Delta.

Salvage did not increase with the rising exports as in 1981 possibly because summer outflows were higher in 1993 and smelt were distributed further downstream in Suisun Bay than in 1981.

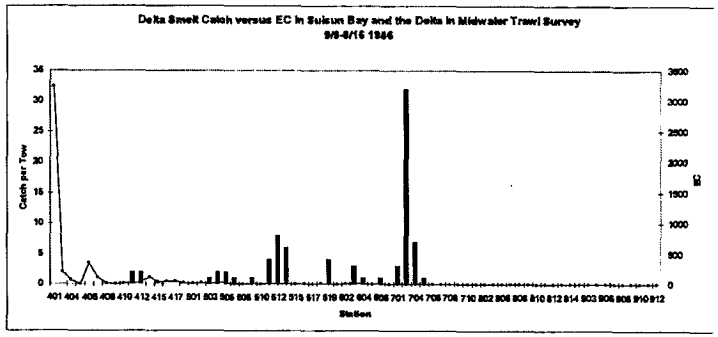
Wet Years

In very wet years such as 1982, 1983, 1986, 1995, and 1998 very few delta smelt were salvaged in the spring and summer because exports were low and outflows were high. Year 1986 is described below as an example of one of these years. Years 1996, 1997, and 1999 were also wet years but had lower spring-summer outflow and behaved more like average or dry water years. These years are described below.

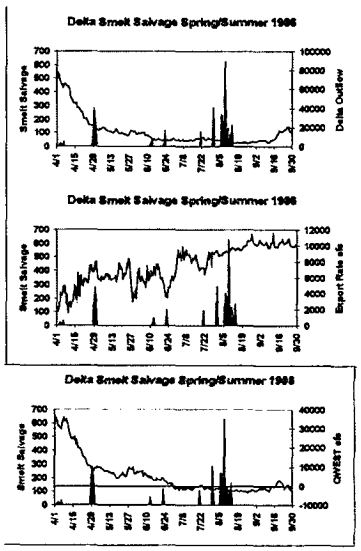
1986. Salvage of juvenile smelt was very low in 1986 because of high Delta outflow. Entrainment of larvae was also low as most larvae were concentrated in or downstream of Suisun Bay based on their distribution data from the Egg and Larvae Survey. Small



numbers were salvaged through the summer as gradually lower outflow brought the brackish water zone progressively upstream. By early summer smelt were concentrated in the lower Sacramento River channel of the western Delta between Collinsville and Decker Island (stations 513, 704, and 706). They remained in these locations into late summer despite higher outflow and lower salinities.

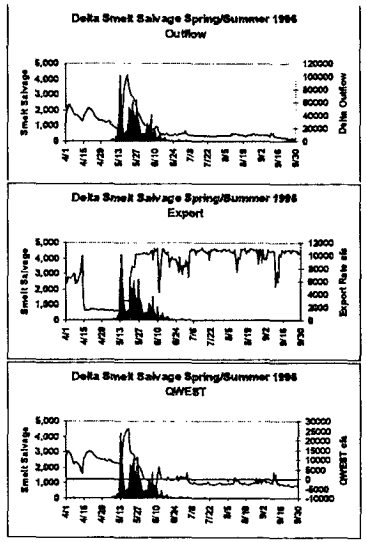


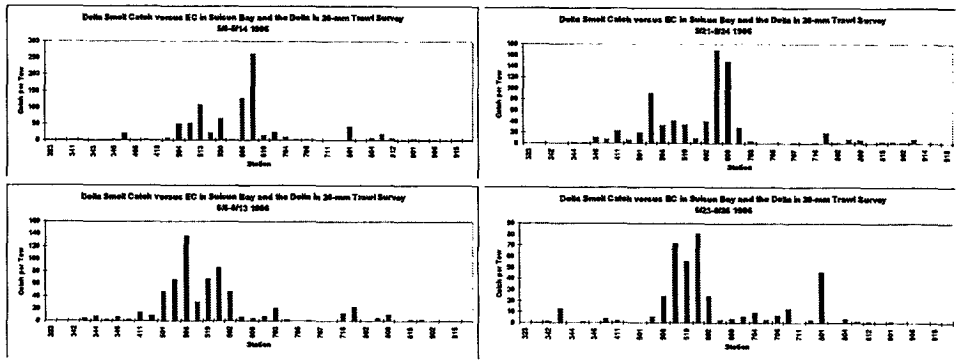
Relatively low numbers of smelt were salvaged in midsummer as exports increased to high levels (>8,000 cfs), outflows fell below 10,000 cfs, and QWEST fell to -2,000 cfs. After outflow and exports stabilized after mid August, salvage was negligible.



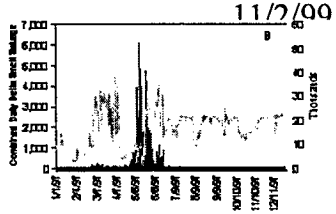
1996. Salvage in the spring of 1996 began to increase in mid May as smelt reached salvageable size under low exports and falling outflow. Salvage decline during the third week of May coincident with a peak in outflow to 100,000 cfs. Later in May salvage increased sharply coincident with a sharp rise in export rate and sharply falling outflows and QWEST. Relatively high salvage rates continued until mid June when outflow, exports, and QWEST stabilized.

In May and June juvenile smelt were concentrated in Suisun Bay (stations 501-602) after the relatively high spring outflow. Small numbers were also collected in the lower San Joaquin River and Middle and Old Rivers (800 and 900 stations). These fish were apparently being drawn out of Suisun Bay and the western Delta by the high export rates in combination with sharply falling outflow and QWEST.



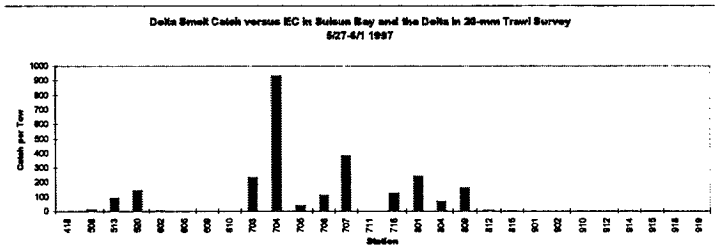


1997. Juvenile smelt salvage in 1997 followed a pattern similar to 1996. Salvage increased in mid May with smelt reaching salvageable size in combination with higher exports. Salvage declined sharply when exports were reduced in mid June.

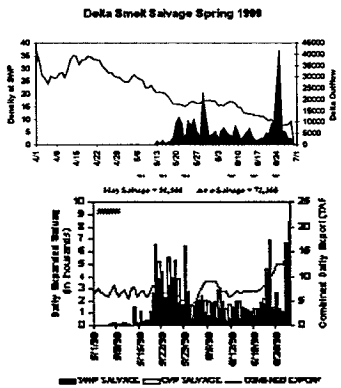


DFG chart of 1997 salvage and exports (Spring 1999 IEP Newsletter) depicting salvage versus acre-feet of exports. Note 30 TAF is equal to approximately 15,000 cfs.

Year 1997 was drier in spring and juvenile smelt were distributed further upstream in the lower Sacramento River (stations 703-707) and the lower San Joaquin River (stations 801-809).



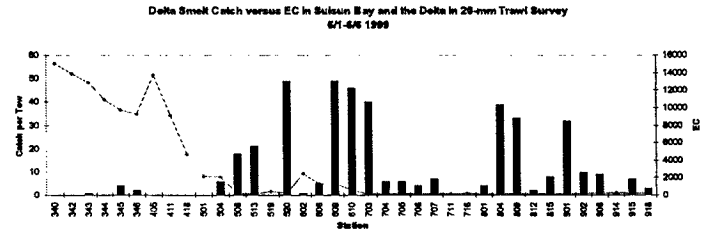
1999. In 1999 salvage of juvenile smelt began as in many of the previous years about mid May when young smelt reached salvageable size. Salvage density was relatively high through mid June and increased sharply at the end of June. Unlike 1996 when outflow, exports, and QWEST stabilized in mid June, in 1997 outflow fell and exports increased into the last week in June. The increase in export rate the last week in June when outflows were falling probably contributed to the peak in salvage at that time.

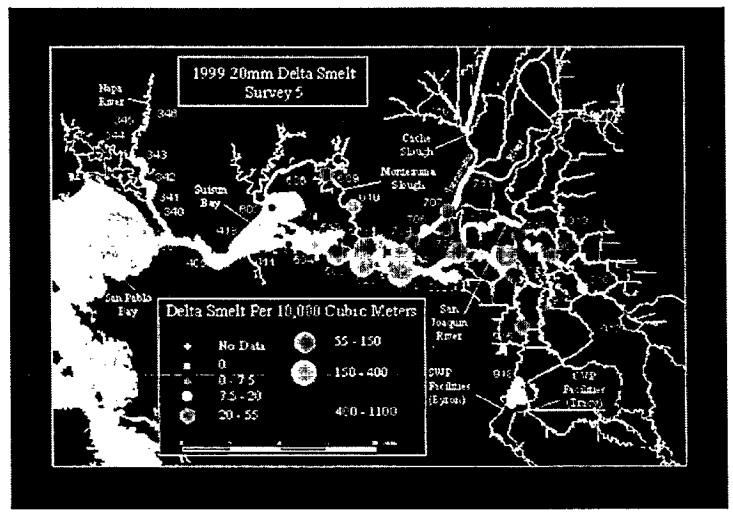


DFG chart of 1999 salvage and exports (Summer 1999 IEP Newsletter) depicting salvage versus acre-feet of exports. Note 30 TAF is equal to approximately 15,000 cfs.

As a consequence of falling outflow and steady or increasing exports, juvenile smelt were distributed further east in the Delta where they were more susceptible to being drawn to the south Delta pumping plants. This distribution pattern is similar to the late May 1993 pattern described earlier. Another possible explanation for the relatively high catch in the central and south Delta could be the relatively low export rates in May of 1993 and 1999. The low export rate compared to earlier years with similar outflows may limit smelt movement to the south Delta pumping plants. The low rates may be sufficient to draw smelt from the western Delta, but are not high enough to pull all of them to the pumps.

McIntire (IEP Fall 1999 Newsletter) suggests a portion of delta smelt population remained in the Delta longer than usual in spring because of cooler water temperatures thus contributing to the high salvage rates through June.





Discussion

The following is a discussion of factors evaluated and their effects on salvage of delta smelt at the south Delta pumping plants. Implications of salvage losses on the delta smelt population are also discussed.

Effect of Delta Outflow on Delta Smelt Salvage

Low outflow in early winter and in late spring increases the entrainment risk to delta smelt adults and juveniles, respectively. First, larval, juvenile, and adult smelt are confined to the Delta in low-outflow periods as brackish water moves upstream into the western Delta, whereas in higher-outflow periods smelt are distributed downstream into Suisun Bay and San Pablo Bay. Low outflow also accentuates the effect of exports on Delta hydrology and smelt movement and vulnerability to salvage in response to hydrological conditions. Falling outflow is a particular concern in spring and early summer, as many salvage events at this time are related to falling outflow coincident with steady or rising exports.

Effects of Reverse Flows in the Lower San Joaquin River (QWEST)

Reverse flow in the lower San Joaquin River downstream of the mouth of Old River, as commonly measured by the QWEST parameter, is an important factor in the potential risk of delta smelt to entrainment at the south Delta pumping plants. QWEST is basically a function of Delta inflow and the export rate, with some adjustment for the amount of inflow from the San Joaquin River and whether the Delta Cross Channel is open or closed and contributing to export demand. QWEST is real in the sense that it is a gross measure of net tidal flow in the lower San Joaquin River toward the south Delta pumping plants. Negative or sharply falling values of QWEST appear to affect the smelt distribution in the Delta and are coincident with many salvage events. QWEST flow, though small in comparison to ebb and flood flow, is measurable and is negative when exports overwhelm net inflows from the rivers.

When QWEST is negative or sharply falling, smelt appear to be drawn upstream in the lower San Joaquin River and toward the central and south Delta. This may be a behavioral phenomenon particularly in the spring and summer when larval and juvenile smelt are "dropping" downstream from freshwater spawning habitats to brackish water rearing habitat in the western Delta and Suisun Bay. Instead of moving to the Bay, they move downstream toward the pumps. This is also a transition condition as hydrology comes under control of the projects, when inflows are falling and exports are stable or increasing.

The most dramatic case of this transition condition occurred in April 1981 when outflow fell from the 1st to the 18th from 33,000 cfs to 111 cfs (more on this later). Smelt concentrated at the upstream end of brackish water in the western Delta and eastern Suisun Bay moved upstream with the salt front into the central Delta via the lower San Joaquin River channel. From there the smelt were drawn toward the export pumps in the south Delta. As in this event, if exports are increasing when outflow is declining, there is a relatively rapid movement of water upstream in the lower San Joaquin River that is

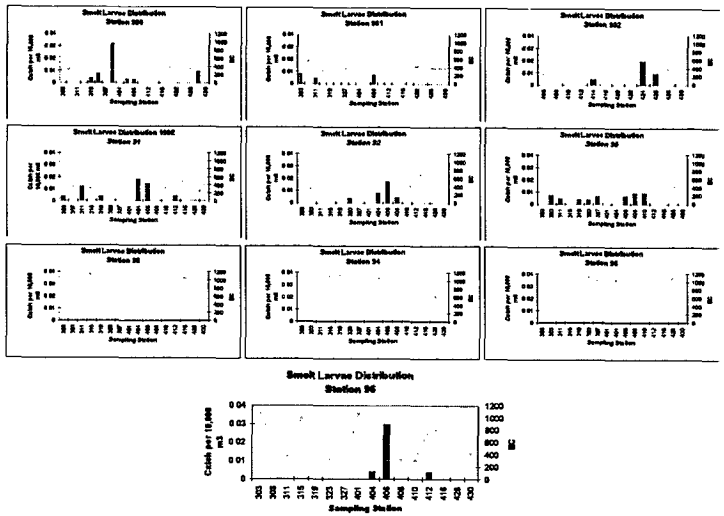
represented by a sharply falling and negative QWEST. Many salvage events are associated with this condition. Such an event could be further accentuated if it occurs during the two periods of the month when tides are filling the Delta.

Salvage events are also initiated simply by increasing exports under stable outflow or stable exports and decreasing outflow. Increased exports result in more negative QWEST. Smelt concentrated at the salt water front in the western Delta are "pulled-away" from the front as brackish water is entrained into water drawn eastward in the lower San Joaquin River. This occurred in July of 1989, when the distribution of juvenile delta smelt shifted from the western Delta upstream toward Old River under increasing and high exports. A similar event occurred in mid-May of 1993. Perhaps the best example of such an event is late June of this year (1999) when exports were increased after an extended period of limitations to reduce delta smelt salvage.

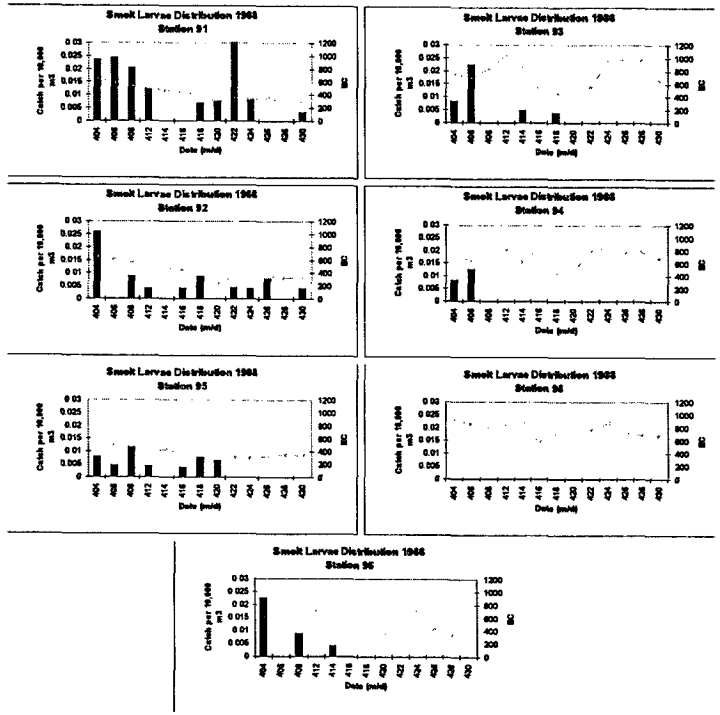
A further indicator of this phenomenon is the pattern of high concentrations of delta smelt in the western Delta and at the pumping plants in the south Delta, and low concentrations in between. One hypothesis is that the smelt in the south Delta are from an isolated population. Another hypothesis is that high smelt-density water of the western Delta is mixed with low density Sacramento River water and drawn up Delta channels to the south Delta pumps. The smelt then concentrate in front of the pumping plants[1] and appear in salvage collections at higher densities than observed in Old or Middle Rivers or the lower San Joaquin channel.

[1] DFG has observed concentrations of delta smelt five times higher in front of the CVP than in the facility.

The South Delta Egg and Larval Study provides more evidence of this phenomenon. During March and April 1992, channels in the central (stations 930-932) and southern Delta (stations 91, 92, and 95) conveyed low-EC Sacramento water and delta smelt larvae to the State Water Project pumping plant. Whereas more eastern channels with higher-EC San Joaquin water (stations 93, 94, and 98) held no smelt larvae. Station 96 near the Tracy Pumping Plant intake had a mixture of the two water types and intermediate catches of smelt.



This pattern can also be seen in the April 1988 South Delta Egg and Larval Study data. Stations 91, 92, and 95 were in Old and Middle River channels conveying low EC Sacramento water, whereas stations 93, 94, and 98 on the east side of the south Delta conveyed more of the higher EC San Joaquin water. Again, station 96 had a mixture of the two types.



Similar patterns were observed in the 1993 and 1994 South Delta Egg and Larval Study data (not shown). Few larvae were collected in the 1995 study, as they were most likely concentrated downstream in Suisun Bay as in 1986 another very wet year.

Effects of Export Rate on Delta Smelt Salvage

High salvage events can occur at low, medium, and high export levels, but are most prevalent at moderate (6,000-8,000 cfs) and high (>8,000 cfs) export levels. High salvage rates can occur under low exports (<6,000 cfs) if exports are increasing as outflow is falling (e.g., spring 1999). High export levels can lead to adult smelt salvage events even in high outflow periods in winters of wet years (e.g., winters of 1982, 1993, 1995, and 1996). Generally high export levels do not lead to juvenile salvage events in spring or summer when outflow is high.

High-export levels do not always lead to salvage events. Generally smelt salvage is low from September into January even at high export rates. Salvage of adults does not increase until the smelt move upstream during their spawning migrations, which appears to be in January or February. Adult smelt salvage is often low in late winter (February and March) even under high exports, especially after earlier winter salvage peaks. Low late winter salvage may be in response to spawning or a spawning die-off. High exports in April also do not cause salvage events, because larvae and juveniles have not reached sufficient size to be salvaged. Finally, late summer salvage is often low under high exports, as a result of juvenile smelt dropping downstream to brackish water under stable hydrology conditions. When both outflow and exports become stable, salvage tends to decline.

Low-export levels (<6,000 cfs) may lead to juvenile smelt salvage events in spring if outflow is low or falling sharply (e.g. 1981, 1994, and 1999). Generally low-export levels are not problems for adults at low or high outflow levels, or for juveniles at moderate to high outflow levels.

Another export factor that may have a bearing on salvage is the "big gulp" feature of the SWP intake system. With Clifton Court Forebay filling around the incoming and high tide portions of each day, smelt may be drawn toward the south Delta and into the forebay where they are much more likely to be lost to predation or export. This may explain why the SWP smelt salvage is often higher than the CVP salvage. Another reason for higher SWP salvage is the feature discussed earlier wherein the low-EC water of the western Delta is drawn into Clifton Court Forebay, while the Tracy plant is drawing in higher EC water with less smelt from the eastern Delta and upper San Joaquin River.

Effects of High Exports on the Distribution of Delta Smelt

High exports are a key factor in delta smelt entrainment not only because more delta smelt are entrained, but also because higher exports shift the distribution of delta smelt in the Delta and make them more vulnerable to entrainment. Under stable "controlled" conditions where brackish water is kept just downstream out of the "influence" of the pumping plants, higher exports are balanced by higher inflows usually from the Sacramento River. Higher inflows from the Sacramento River flush brackish water (and delta smelt)

> *"When not spawning, delta smelt tend to concentrate just upstream of the entrapment zone in the vicinity of the 2-ppt salinity isohaline." (DFG 1996)*

from the lower Sacramento River channel, where historically the brackish zone (and delta smelt) extended under equivalent Delta outflows. Greater negative flows in the lower San Joaquin River between Antioch and the mouths of Old and Middle rivers also shift delta smelt eastward. Flushing of the lower San Joaquin River with Sacramento River water heading for the export pumps may also reduce the value and use of this historical brackish water habitat to delta smelt.

Effects of Exports and Entrainment Losses on the Delta Smelt Population

The effect of exports on fish populations is a continuing issue among the parties involved in the CALFED program. CALFED recently included a quote from its Diversion Effects Fish Team in its Strategic Plan for Ecosystem Restoration: *"it is not clear to what extent entrainment affects the population size of any one species of fish or invertebrates."* The Winter IEP Newsletter related the following from a recent delta smelt workshop: *"Interpretation of delta smelt salvage levels in terms of population effects remained unresolved."* Water users are continually being asked to potentially limit their water supply to reduce losses of smelt and other fish at the export pumps when no one has shown that the losses at the pumps are affecting the population size and viability. Hundreds of millions of dollars may be spent in the future to upgrade the fish facilities at the south Delta pumping plants to reduce entrainment effects if determined to be a benefit to the delta smelt and other fish populations.

Have salvage losses contributed to the documented decline in delta smelt over the past two decades? This question has been debated because the smelt population declined sharply from 1981 to 1984, a relatively wet period. Many believe that high outflows in 1982 and 1983 contributed to the decline. Poor food supply and cold water, along with smelt young being washed downstream into San Francisco Bay may have contributed.

> *"The decline became precipitous in 1982 and 1983 due to extremely high outflows." (DFG 1996)*

Analysis of salvage and fish survey data indicates otherwise. Entrainment of delta smelt was also a likely major factor in the decline as large losses of smelt were apparent in 1981 and 1982.

1981. In 1981, 75,000 adult smelt were salvaged in the winter and 380,000 juveniles were salvaged in the spring and summer. Factoring in a salvage efficiency of only 60% for adults (it is less for juveniles), entrainment losses are conservatively estimated at 750,000 juveniles and adults. Factoring in predation at the fish facilities and Clifton Court Forebay (where the majority of salvage occurred), which has been estimated at higher than 80% for salmon smolts, entrainment related losses of salvageable size delta smelt in 1981 would be nearly 4 million.

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The majority of spring-summer salvage (about 200,000) occurred from mid May through early June. Taking into account a typical size frequency distribution (from the 1996 20-mm survey) for that time of the year, loss of smelt that are too small to salvage from mid May to early June would conservatively be about equal to the salvage estimate (about 200,000). Again factoring in predation would add another approximately 1 million smelt to the total loss estimate above.

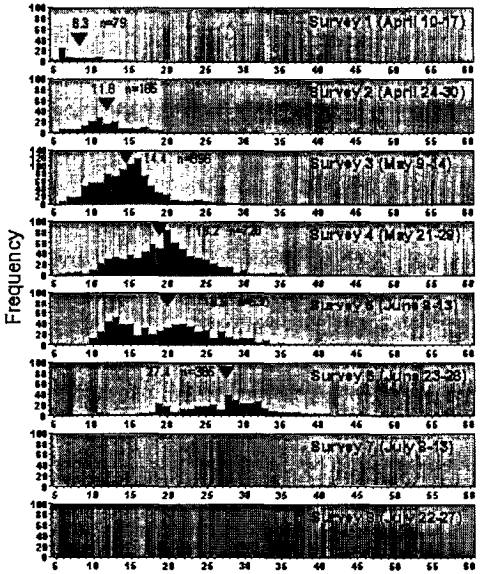

Chart of delta smelt 20-mm survey data from 1996. (Source: DFG web site)

Factoring in pre-salvageable larvae and early juvenile from early April through mid-May would add further to the loss estimate. Exports in April of 1981 averaged 8,000 cfs. The high exports led to QWEST's as low as –6,000 cfs. Delta outflow declined from 33,000 on April 1st to 110 cfs on April 18th. This unprecedented decline in outflow under high export conditions likely drew many newly hatched larvae to the south Delta pumping plants. During the minimum flow periods, 10,000-20,000 acre-ft of freshwater habitat per day were being drawn from the western Delta upstream toward the south Delta pumping plants. From April 30 to May 3 outflow was about 500 cfs and exports were near 10,000 cfs. With Delta inflow barely matching exports, many young smelt were likely dropping "downstream" toward the south Delta pumping plants.

In addition to the entrainment losses, the freshwater habitat zone of the Delta was being exported. Juvenile smelt and other estuarine and anadromous fish depend upon this habitat as a nursery area. This freshwater habitat develops spring plankton blooms to support the young smelt. When this habitat is exported it is replaced with low-productivity "Shasta" water. This may explain the relatively poor growth or small size exhibited by delta smelt in the lower San Joaquin River observed in the 20-mm survey in 1996.

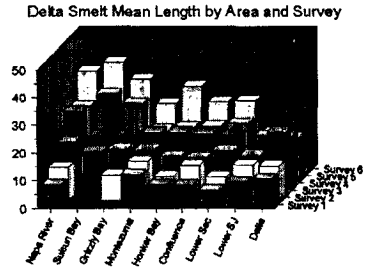

Chart source: DFG web site.

It is fortuitous that exports dropped in May 1981 otherwise losses would have been even greater. From May 15 to June 7, nearly 140,000 smelt were salvaged (about 6,000 per day), while exports averaged only 3,700 cfs. Both pumping plants essentially shut off on June 8 and salvage drop sharply. Between June 9th and July 17th salvage remained low and sporadic and the state project pumped less than 1,000 cfs keeping total exports at 4,000-5,000 cfs. However, as exports rose to 10,000 cfs in late July salvage increased sharply and averaged 4,000 per day from July 23-August 15.

1988. Like 1981, outflow fell to near zero in May and June of 1988. Salvage was high and larval entrainment was also likely high with high exports through April into mid May. With the high losses the fall mid-water trawl survey population index in 1988 was very low at about 250.

1996. In 1996 events were not so fortuitous as exports increased in mid May rather than declined as outflow was falling. Exports reached 10,000 cfs in the third week in May (see previous chart) and continued at that level through the summer. Low VAMP exports from mid-April to mid-May provided some protection, however the sharply higher exports beginning in mid-May brought smelt salvage to 1,000-4,000 per day. With most of the smelt in the estuary below salvageable size (see chart above on page 26) in May, entrainment losses of pre-salvageable size smelt were likely extremely high. The entrainment losses combined with the high salvage losses probably led to the poor population index (about 250) in the fall of 1996 after somewhat of a recovery in 1993 and 1995.

1997. Year 1997 though classified a wet year was similar to 1981 in terms of spring-summer hydrology. Export rose in mid-May after the VAMP period to approximate 15,000 cfs and remained near 10,000 cfs for most of the summer. Salvage of smelt was high from mid May through mid June. Larval losses were probably high in early April under low outflow and high exports. The population index was again poor in 1997 at 361 as compared to near 2000 in 1995 and 1993.

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1999. The population loss in 1999 was also likely high with similar conditions and salvage losses as 1981 and 1996. Again falling outflow in combination with rising exports were the likely cause of smelt being drawn to the south Delta pumping plants in high numbers. Perhaps a greater affinity for the Delta in 1999 also contributed to the high salvage. Efforts made to limit exports through the spring likely helped to maintain a September population index of 198.

Summary of Population Effects. Delta smelt are unique in that their entire population is concentrated for most of the year in the freshwater and low salinity pool at the head of the estuary. In very wet years this habitat extends through the Western Delta, Suisun Bay, Montezema Slough, Suisun Marsh channels, Carquinez Straits, and eastern San Pablo Bay. In dry and moderate water years like 1981 the population is concentrated in the lower Sacramento River and lower San Joaquin River channels of the western Delta. Even in wet years with drier springs like 1996, 1997, and 1999 large portions of the population are vulnerable to entrainment and salvage loss. This "dry" year distribution makes the population very vulnerable to the effects of south Delta exports. It also explains why the delta smelt population often does not respond positively to all "wet" years

The events of years 1981, 1988, 1996, 1997, and 1999 are extreme examples of this vulnerability. If it were not for reduced exports for part of the spring and early summer of each of these years perhaps much of the population would have been lost. As it was in 1981 and 1996 the smelt population took two of its sharpest drops on record. Such vulnerability to the population is even greater than years 1989-1992, which exhibited higher indices than 1988 despite being under extended drought conditions. In these years exports and outflow were often low and more stable due to lack of water supply for export. Exports were especially lower in May and June.

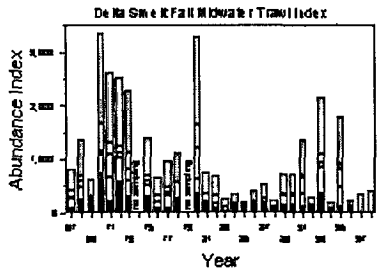
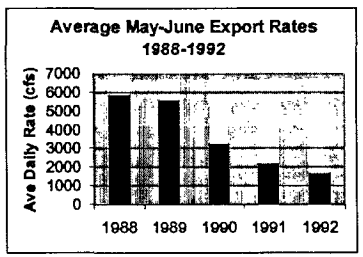


Chart source: IEP newsletter. (Note: top section of bar is September index – bottom is December. Last year is 1998.)



What Can Be Done to Reduce Entrainment Losses

The 1995 Delta water quality standards and more recent actions such as the VAMP would alleviate many of the acute salvage events for delta smelt. High winter adult salvage events such as in 1981 would be lessened by the X2, outflow, and E/I

standards, which ensure against very high exports and very low outflow. May-June salvage events like those experienced in 1981, 1984, and 1988 would be at least partially alleviated by the VAMP and E/I standards. The VAMP and E/I standard would also alleviate the extreme spring low outflow events in 1981 and 1988 when outflow fell to near zero and likely lead to high larval entrainment.

Other salvage events not alleviated by standards or VAMP, such as some winter adult and summer juvenile events, can be treated with a combination of increased or stabilized outflow and reduced or stabilized exports. Many of these treatments have been suggested and tried over the past several years and have helped to reduce salvage of delta smelt particularly in 1997 and 1999. Sharply falling outflow and increasing exports in spring are of particular concern because the combination appears to draw many juvenile smelt to the south Delta (e.g., 1981, 1984, 1993, 1994, 1996, 1997, and 1999). These events are also avoidable. Stabilizing or increasing outflow and QWEST, or reducing or stabilizing exports may reduce salvage losses. QWEST can be increased in low outflow years by opening the Delta Cross Channel and Head-of-Old-River barrier, or possibly by increasing San Joaquin inflow. Shifting more spring exports to the Tracy Pumping Plant in drier years when exports are limited could reduce smelt entrainment. Increasing exports to high levels in early summer under low outflow should also be avoided (e.g., 1981, 1988, 1989, and 1999). Water resources and project operation capabilities available in the future under CALFED's Water Management Program should help toward balancing outflow and export conditions to reduce entrainment losses and protect the habitat of delta smelt.

There are other factors not discussed in this paper that may also affect delta smelt entrainment. For example, the "big gulp" at the intakes to Clifton Court Forebay may be a factor in drawing smelt to the south Delta. It may explain why salvage is much higher at the SWP than at the CVP intakes. Changes to pumping plant intakes and the south Delta channel configuration may help to alleviate these potentially contributing factors. Other factors could be water temperature, the spring-neap tide cycle, and weather (e.g., wind and barometric pressure).

Summary and Conclusions

General Patterns

1. Spring-summer salvage is lower in years with greater spring outflow, because more adult smelt are spawned west of the Delta, and larvae and juvenile smelt are transported west of the Delta.
2. Total spring-summer salvage appears unrelated to total spring-summer export, although low exports in portions of the spring and summer of 1990-1992 likely contributed to lower salvage during the spring-summer of those years.
3. Salvage of adult smelt in fall and winter appears related to total population abundance, with high abundance years (1980-1982) having the highest salvage.
4. Fall-winter salvage appears unrelated to total fall-winter exports with the possible exception of 1994, which had low salvage and low exports.

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Fall Pattern

5. Fall salvage is generally very low regardless of year type, population abundance, outflow, and export rate, because pre-spawning adult delta smelt have a strong affinity for low-salinity water in the fall.

Winter Pattern

6. Winter salvage occurs predominantly in January in most years with low salvage in February and March even under high exports and low outflow.
7. Winter salvage was higher in high abundance years and high salvage events occurred longer into the winter (1980-1981).
8. Winter salvage of smelt increases as some smelt move upstream into freshwater portions of the Delta to spawn.
9. Winter salvage of smelt is higher even in wet years if export rates are high (8,000-14,000 cfs).
10. Winter salvage of smelt is generally more problematic if smelt move upstream prior to the onset of peak winter flows.
11. Winter salvage is higher even after peak winter flows when outflow and QWEST fall and exports increase above 6,000 cfs.
12. Winter salvage generally declines dramatically when outflows are high and exports are low, or when outflow and exports rates become stable.
13. Winter salvage may increase regardless of outflow if exports are greater than 10,000 cfs.
14. Winter salvage may have greatest effects on the delta smelt population in low-abundance drought years like 1988 and 1989 that have low outflow and high export rates.

Spring-Summer Pattern

15. Salvage generally increases in mid-May as smelt develop to salvageable size.
16. Peaks in spring salvage often coincide with rising or moderate to high export rates (>6,000 cfs), low (<10,000 cfs) or declining outflow and falling or negative QWEST.
17. Peaks in summer salvage often coincided with high export rates (>8,000 cfs), low outflow (<10,000 cfs), and highly negative QWEST (< -2,000 cfs), which allow delta smelt concentrated in the western Delta to be drawn into the south Delta.
18. Salvage rates generally drop by summer as outflow, exports, and QWEST stabilize, and delta smelt juveniles move west toward the Bay.
19. Spring-summer salvage rates, like winter rates, are related to population abundance.
20. In very wet years (1982, 1983, 1986, 1995, and 1998) very few delta smelt are salvaged in spring and summer because exports are low, outflows are high, and smelt are distributed west of the Delta.
21. Larval entrainment likely occurs in April and May, and is likely most prevalent in drier springs when outflow is low and exports are high.

Effect of Salvage on Delta Smelt Population

22. The well-documented decline in the delta smelt population as best observed in the fall mid-water trawl survey index appears related to high larval entrainment and high adult and juvenile salvage. Sharp drops in the population index in 1981, 1985, 1988, 1994, and 1996 are related to high entrainment-salvage. Recoveries in 1991, 1993, and 1995 are related to low exports and salvage rates in the spring.

Potential to Reduce Entrainment-Salvage and Increase Population

23. The Water Quality Control Plan outflow and export/inflow standards and VAMP eliminate many of the risks to the delta smelt population from entrainment-salvage. What risks remain are the potential effects of moderate to high exports in January and the pre-VAMP and post-VAMP periods (early April and late May and June). These risks can be reduced with CVPIA (b)(2) and CALFED Environmental Water Account resources that reduce exports or increase inflow into and through the Delta.

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